PARASITES OF THE WOUNDFIN MINNOW, *PLAGOPTERUS ARGENTISSIMUS*, AND OTHER ENDEMIC FISHES FROM THE VIRGIN RIVER, UTAH

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ABSTRACT.—Two hundred woundfin minnows, *Plagopterus argentissimus*, from four sites along the Virgin River, Utah, were examined on two dates during summer 1985. The foreguts of 211 woundfin and variable numbers of other fishes from the Virgin River near Beaver Dam Wash, Arizona, and Mesquite, Nevada, were examined for cestodes on four dates throughout 1979. Seven parasites were found in *P. argentissimus: Posthodiplostomum minimum* (metacercariae), *Diplostomum spathaceum* (metacercariae), *Bothriocephalus acheilognathi, Gyrodactylus* sp., *Lernaea cyprinacea, Trichodina* sp., and *Ichthyophythirius multifiliis.* Fungal infections were noted on two fish during the study. Seventeen Virgin River roundtail chub, *Gila robusta seminuda*, were examined from two of the four sites in 1985 and 64 specimens from Beaver Dam Wash were examined in 1979. *Gila robusta seminuda* was infected with *Posthodiplostomum minimum* (metacercariae) and *Bothriocephalus acheilognathi*, the Asian fish tapeworm. This cestode probably gained entrance into the ichthyofauna of the Virgin River from red shiners, *Notropis lutrensis*, and has the potential of being very detrimental to the endemic and endangered fishes of the Virgin River. Parasite loads were correlated with water quality and habitat disturbance, with highest number and frequency occurring in "disturbed" sites. Low river flows and increased total dissolved solids appear to be associated with a higher parasite frequency and mean number in fishes of the Virgin River. These data represent the first known published records for parasites of the woundfin minnow and Virgin River roundtail chub.

There is a paucity of information on the parasitofauna of the woundfin minnow, *Plagopterus argentissimus*, and other species of fish from the Virgin River, Utah-Arizona-Nevada. Many of the fishes in the Virgin River are endemic and have been listed as endangered species, the woundfin included. Hoffman (1967) lists no parasites for the woundfin. Other common fishes in the Virgin River drainage include the Virgin roundtail chub, *Gila robusta seminuda;* speckled dace, *Rhinichthys osculus;* Virgin spinedace, *Lepidomeda mollispinis;* desert sucker, *Catostomus clarki;* flannelmouth sucker, *Catostomus latipinnis;* and the introduced red shiner, *Notropis lutrensis*. Parasites of these later species are also poorly known (Hoffman 1967). Parasites can have adverse effects on fish populations. Changes in incidence, intensity, or parasite species infecting or infesting a host can provide important clues to the health and status of fish host populations. To understand management options, it is essential to also know the life cycle of the parasite and its effects at various levels of infection. For example, parasitism can be responsible for reduced growth rates, reduced egg production, poor swimming performance, aberrant behavior, etc. (David 1947, Dogiel 1958, Hoffman 1967).

The primary objectives of this study were as follows:

1. Identify the species of parasites inhabiting the woundfin minnow at selected sites in the Virgin River in Utah.
2. Determine the frequency of occurrence, abundance, and temporal variation of parasites for *P. argentissimus* in the summer during the normal period of low flow.
3. Determine the relationship between parasitism and the immediate habitat of the host.
4. Determine the pathogenicity of the parasite to the host.

In a previous study conducted during 1979 (Greger 1983), woundfin minnows examined during February and June near Beaver Dam Wash, Arizona, were not parasitized by cestodes. Cestodes were present, however, in the foreguts of *P. argentissimus* and increased in both number and frequency from September to December. Frequency of infection of woundfin with cestodes was much less near Beaver Dam Wash, Arizona, than was true further downstream in Nevada. This suggested that woundfin may be more vulnerable to parasitism in an agriculturally disturbed habitat than in a more natural environment. Because the Virgin River near St. George,

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Utah, exhibits similar agricultural disturbances, our hypothesis was that the parasite load in the fish population near St. George would be higher than in the less disturbed sections of Virgin River in Utah.

The life cycles of cestodes and other parasites of fishes from the Virgin River have not been determined in detail. In general, fishes can be both definitive and intermediate hosts for cestodes. Reproductively mature adult cestodes present in fish will release eggs from gravid proglottids while in the intestine of the host. The eggs passs through the host's anus and may settle in the stream sediments. For many cestodes, increasing temperature causes the operculate eggs to hatch, releasing a ciliated coracidium (motile oncosphere). Cyclopoid copepods (first intermediate host) ingest these larvae and become infected. The oncosphere sheds its ciliated coat in the gut of the copepod and burrows through the intestinal wall to the hemocoel, where it develops into a procercoid larvae (Cheng 1973). This mesacestode-type larva cannot become infective to a definitive host for about two to three weeks, until cercomer formation (Cheng 1973). If a fish ingests an infected copepod, the adult cestode may commence development in the intestine of the host. Although larval (pleroceroid) development in a second intermediate host (such as a smaller fish) is possible, it is unlikely to occur in the Virgin River ichthyofauna, since no primarily piscivorous fishes are present. It seems more probable that development of the adult cestode in Virgin River fishes occurs following ingestion of an infected copepod. Direct development of the adult pseudophyllidean cestode *Eubothrium salvelini* following ingestion of infected *Cyclops* sp. by Sockeye salmon, *Oncorhynchus nerka*, has been reported by Smith (1973) from a lake in British Columbia.

The effects of adult cestodes upon fish hosts have not been studied in detail. Rees (1967), after an extensive review of the literature, reached no definitie conclusions regarding the lethal effects of adult cestodes. Other investigators have suggested that adverse effects are considerable. Smith (1973) reported that noninfected salmon smolts grew 5%–7% longer and 17%–24% heavier than infected smolts. Field observations and swimming performance tests suggested cases of reduced swimming abilities and earlier fatigue in salmon and trout infected with helminths (Smith and Margolis 1970, Heckman 1983). These data also demonstrate some nutritional or growth impairments for infected fish. Other researchers (Wardle 1933, Dogiel 1958, Dombroski 1955) have reported that adult pseudophyllidean cestodes can affect host nutrition and survival. Severe occlusion (impaction) of the gut has been reported for infected salmon (Dogiel 1964) and appeared to affect the nutritional status in severe cases. Impaction by parasites would also affect reproductive potential. Williams and Halvorsen (1971) negated the belief that contents of the fish host intestine represent an unlimited source of food for cestodes. Impaction and reduced growth and vigor would also reduce reproductive potential.

Other indirect effects of cestode adults on their hosts have been demonstrated in the laboratory. Boyce and Clarke (1983) determined that Sockeye salmon yearlings infected with tapeworms had a reduced ability to adapt to seawater as evidenced by increased mortality and elevated plasma sodium levels. Boyce and Behrens-Yamada (1977) also reported Sockeye salmon juveniles infected with the same cestode, *Eubothrium salvelini*, to be more sensitive to zinc toxicity. These effects could make the infected fish less vigorous and more susceptible to predation during its seaward migration.

The Asian fish tapeworm, *Bothriocephalus acheilognathi*, introduced into this country by imports of grass carp, has been described as a dangerous parasite in Europe (Bauer et al. 1981). This cestode has apparently become established in the ichthyofauna of southern Utah.

The most common fish parasite found in this survey was the metacercarial state of the digenetic trematode, *Posthodiplostomum minimum*. "Black spot," for example, is caused by metacercarie found in melanin-pigmented cysts in the skin. This larval stage of flukes may be found in all tissues of fish (Spall and Summerfelt 1969b).

MATERIALS AND METHODS

The 1979 collections were made in February, June, September, and December near Beaver Dan Wash, Arizona, and Mesquite, Nevada (Fig. 1). At each location, the foregut

Fig. 1. Fish sampling sites along the Virgin River, Utah, Nevada, Arizona, for this study.

TABLE 1. Rating scale to indicate approximate density of the metacercarial infection in Virgin River fishes.

Assigned scale number	Average number of metacercariae per microscopic field at 20X
0	None
1	1–9
2	10–19
3	20–29
4	30–39
5	40–TNTC

of 22–34 woundfin and variable numbers of other species was examined. Because the 1979 study was conducted as a part of a study of food habits (Greger 1983), we looked only for cestodes in the foregut.

The 1985 collections were taken from the Virgin River on 27 and 28 July and 23, 24, 25, and 31 August 1985. Collections were made about 1/4 mile downstream from the inflow of the Santa Clara River, at Twin Bridges, about two miles below Berry Springs, and at Hurricane Bridge in Utah, and downstream in Nevada near Mesquite (Fig. 1). At each location 23–25 *P. argentissimus* and variable numbers of other fish species were examined. At Mesquite we examined 88 red shiners.

In 1985 external examination for parasitism was made immediately following death of the fish. Scrapings of mucus and epithelial cells were taken from the gill surface, the base of the fins, and the lateral surface of the body. Scrapings were mixed in physiological saline and examined at 100X and 430X. Blood samples were obtained from peripheral circulation on microscope slides, air dried, and later stained (Giemsa-Wright combination) prior to examination at 430X and 1000X. Each blood slide was examined for a minimum of 10 minutes.

The abdominal cavity was opened ventrally and internal organs were examined. Each organ was removed and placed in a saline solution prior to examination with a dissecting microscope. Eye tissues, including the lens, were also examined.

Cestodes were excised from the intestinal tract, enumerated and fixed in AFA. Some individual worms were prepared for examination by scanning electron microscopy by fixation in 3% gluteraldehyde with an acrolein buffer.

Viscera and gills from two woundfin from each of the four sampling locations were fixed in buffered 10% formalin and prepared for tissue evaluation at the Brigham Young University laboratory. These samples were processed by standard methods, stained, and examined closely to evaluate parasite pathology. Two stains, trichrome, and hematoxylin and eosin were used for the tissue sections.

During the first day of study it was noted that many fish were heavily parasitized by metacercariae of the trematode, *Postho-*

TABLE 2. Summary of parasite data from woundfin captured at each of four locations 27–28 July (N = 25) and 23–25 August (N = 23). August data are in parentheses.

Sample location	Average total length		*Posthodiplostomum* Percent		*Posthodiplostomum* Average scale number		Number with other disease problems	
Twin Bridges	76.4	(75.7)	100	(96)	5.0	(4.0)	3/25[a]	(5/23[c])
Santa Clara inflow	69.0	(69.8)	100	(100)	3.6	(2.7)	1/25[b]	(5/23[d])
Hurricane Bridge	74.1	(80.8)	44	(57)	1.0	(1.0)	0	(0)
Berry Springs	70.7	(64.9)	8	(22)	<1.0	(<1.0)	0	(1/23[e])

[a]3/25 Eye fluke (metacercariae), *Diplostomum spathaceum*, fungal growth, dorsal fin.
[b]1/25 Fungal growth, dorsal fin, skin erosion and fungal growth, pectoral fin; *Gyrodactylus*, gills.
[c]5/23 Eye fluke (metacercariae), *Diplostomum spathaceum*, Roundworm, intestine, 3 fish. *Trichodina*, ciliated protozoan (gills), Anchor worm, *Laernea*, 2 fish.
[d]5/23 Eye fluke (metacercariae), *D. spathaceum*, Anchor worm, *Laernea*, 3 fish. *Trichodina*, ciliated protozoan (gills), 2 fish.
[e]1/23 *Trichodina*, ciliated protozoan (gills).

diplostomum minimum. A rating scale was developed to represent different densities of infection (Table 1).

RESULTS

Results of the parasitological examination are presented in Tables 2 to 6. These data show that the "disturbed" segments of the river (Mesquite, Twin Bridges, and Santa Clara inflow) carried a heavier parasite load than in undisturbed segments (Beaver Dam Wash, Hurricane Bridge, and Berry Springs) (Deacon and Hardy 1984). There is further indication that the trematode parasite, *Posthodiplostomum minimum*, in woundfin minnows in the "undisturbed" segment of the Virgin River in Utah may have increased slightly from July to August 1985 (Table 2). Whereas the trematode, *Posthodiplostomum minimum*, was clearly the major parasite infecting woundfin, other parasites were detected on some individuals (Table 2).

A limited number of other fish were also examined for parasites (Tables 3 to 6). Of greatest concern was the presence of the Asian tapeworm, *Bothriocephalus acheilognathi*, in the roundtail chub population.

Table 5 shows frequency of occurrence and mean numbers of a cestode parasite in the foregut of all cyprinids occurring in Virgin River near Beaver Dam Wash, Arizona, in 1979. This cestode was later identified as *Bothriocephalus acheilognathi*. It is evident that frequency of infections varies seasonally and that the roundtail chub is more frequently infected with more tapeworms per fish than are other native species. The introduced red shiner appears to be about as heavily infected as is the roundtail chub. Table 5 also demonstrates that frequency and density of infection tends to increase in all species in September and December.

Table 6 shows that woundfin in the disturbed river segment near Mesquite tend to be more heavily parasitized throughout the year than at Beaver Dam Wash. The red shiner is heavily parasitized by cestodes at both Mesquite and Beaver Dam Wash, but until 1985 remained abundant throughout the year only near Mesquite.

Thirty-seven adult Asian tapeworms were identified from 24 (27%) of 88 red shiners collected in Virgin River near Mesquite, Nevada, on 25 August 1985. Mesquite, like Twin Bridges and Santa Clara inflow, is in a disturbed segment of the Virgin River.

COMMENTS FOR SELECTED PARASITES OBSERVED DURING STUDY

Posthodiplostomum minimum

This was the most common parasite observed in fishes from the Virgin River in Utah. An excellent review article of North American studies of this fish parasite is found in Spall and Summerfelt (1969b). Metacercariae of the strigeid fluke, *Posthodiplostomum minimum* (MacCallum 1921), the white grub, are reported in most American helminthological surveys of fishes. The metacercaria was first reported over a century ago. It is enzootic in the U.S. exclusive of alpine regions and occurs in abundance in many of the 100 species of North American fishes that have been studied to date (Hoffman 1967). The trematode larvae are generally so numerous in the liver, kidney, heart, and other viscera that many

TABLE 3. Results of parasite inventory for other fish species examined from Twin Bridges, 27–28 July (1–12) and 23 August (13–15) 1985.

Species	Fish number	Measurements (mm) TL	SL	Parasites
Flannelmouth Sucker (*Catostomus latipinnis*)	1	115	90	No parasites
Virgin River Roundtail Chub (*Gila robusta seminuda*)	1	160	145	Metacercariae: *Posthodiplostomum*
	2	145	130	Metacercariae: *Posthodiplostomum*
	3	152	139	Metacercariae: *Posthodiplostomum* Asian Tapeworm: *Bothriocephalus*
	4	155	141	Metacercariae: *Posthodiplostomum* Asian Tapeworm: *Bothriocephalus* Anchor worm: *Laernea*
	5	142	130	Metacercariae: *Posthodiplostomum*
	6	136	123	Metacercariae: *Posthodiplostomum*
	7	134	124	Metacercariae: *Posthodiplostomum*
	8	145	132	Metacercariae: *Posthodiplostomum*
	9	135	126	Metacercariae: *Posthodiplostomum*
	10	125	115	Metacercariae: *Posthodiplostomum*
	11	160	145	Metacercariae: *Posthodiplostomum*
	12	145	130	Metacercariae: *Posthodiplostomum*
	13	170	142	Metacercariae: *Posthodiplostomum*
	14	170	138	Metacercariae: *Posthodiplostomum*
	15	135	112	Metacercariae: *Posthodiplostomum*

TABLE 4. Results of parasite inventory for other fish species examined from mainstream Virgin River about 1/4 mile below inflow of Santa Clara River, 27–28 July 1985.

Species	Fish number	Measurements (mm) TL	SL	Parasites
Flannelmouth Sucker (*Catostomus latipinnis*)	1	115	90	No parasites
	2	164	140	No parasites
Largemouth Bass (*Micropterus salmoides*)	1	58	50	Metacercariae: *Posthodiplostomum*
	2	54	47	Metacercariae: *Posthodiplostomum*
Virgin River Roundtail Chub (*Gila robusta seminuda*)	1	155	145	Metacercariae: *Posthodiplostomum* Asian Tapeworm: *Bothriocephalus*
	2	165	146	Metacercariae: *Posthodiplostomum*

TABLE 5. Frequency of occurrence (%) and mean number of the cestode, *Bothriocephalus acheilognathi*, (Order: Pseudophyllidea) from the foreguts of fishes collected from the Virgin River near Beaver Dam Wash, Arizona, 1979. Abbreviations are as follows: R = *Rhinichtnys osculus;* G = *Gila robusta;* L = *Lepidomeda;* P = *Plagopterus;* N = *Notropis lutrensis*.

Month		R	G	L	P	N	F. Ratio
	N	28	20	24	22		
February	%	3.7	35.0	4.1	0.0	ND	
	Mean	0.3	0.6	0.04	0.0		8.18*
	SE	0.1	0.2	0.1			
	N	27	4		26		
June	%	0.0	25.0	ND	0.0	ND	
	Mean	0.0	0.8		0.0		
	SE	0.0	0.8				
	N	29	31	31	28	26	
September	%	18.2	66.6	12.0	10.7	84.6	
	Mean	0.5	2.0	0.2	0.1	3.9	28.04*
	SE	0.2	0.5	0.2	0.1	0.6	
	N	23	9	27	27	27	
December	%	52.0	88.8	7.4	33.0	88.8	
	Mean	2.2	16.8	1.7	0.6	9.3	23.14*
	SE	1.2	6.0	1.7	0.3	2.0	

Note: Asterisks denote a significant difference among species at $p < 0.01$.
ND = No data.
SE is the standard error of the mean.

TABLE 6. Frequency of occurrence (%) and mean number of cestode parasites (Order: Pseudophyllidea) from the foreguts of fishes from the Virgin River in Nevada, 1979. An asterisk denotes a significant difference between species at $p < 0.01$.

Month		*Plagopterus argentissimus*	*Notropis lutrensis*	t
	N	24	48	
February	%	33	69	
	Mean	0.54	2.94	3.94*
	N	23	25	
June	%	13	36	
	Mean	0.13	3.76	2.01
	N	34	29	
September	%	53	86	
	Mean	1.76	6.03	3.45*
	N	27	27	
December	%	37	81	
	Mean	0.63	6.59	5.07*

observers have implicated them as being histopathogenic. The pathogenicity of the larval stage is usually due to compression or occlusion of a vital organ.

Early literature concerning the classification of *Posthodiplostomum minimum* is invested with synonymy and misinformation, partly because of inadequate description and erroneous identification and partly because some larval stages were described before their life histories, especially the adult, were known. Nomenclatural history has been reviewed by Miller (1954), Hoffman (1958), and Bedinger and Meade (1967).

Studies by Hunter (1937) on the transformation of *Cercaria multicellulata* to *Neascus van cleavei* and by Ferguson (1938) on transformation of metacercariae of *N. van cleavei* to adult *Neodiplostomum* culminated in the first description of the life cycle of *Posthodiplostomum minimum*.

Metacercariae have been found in all visceral organs but occur in abundance in the liver, spleen, kidneys, mesenteries, sinus venosus, heart, and ovaries (Figs. 2a, 2b, and 3a, 3b). Some strigeid larvae show positive histotropic effects toward specific fish tissue in vitro (Davis 1936). Avault and Allison (1965) found that the heart, liver, and kidneys contained approximately 79% of the total metacercariae in bluegill (*Lepomis machrochirus*). Metacercariae have not been reported in fish testis, apparently the only visceral organ alien to this parasite.

The occurrence of numerous metacercariae in visceral organs suggests deleterious effects on the well-being of the host and implicates *P. minimum* as a cause of mortality or morbidity. Hunter (1937, 1940) stated that death resulted if sufficient liver or other visceral tissue were destroyed by the metacercariae. Hughes (1928) observed bluegill, which had a heavy

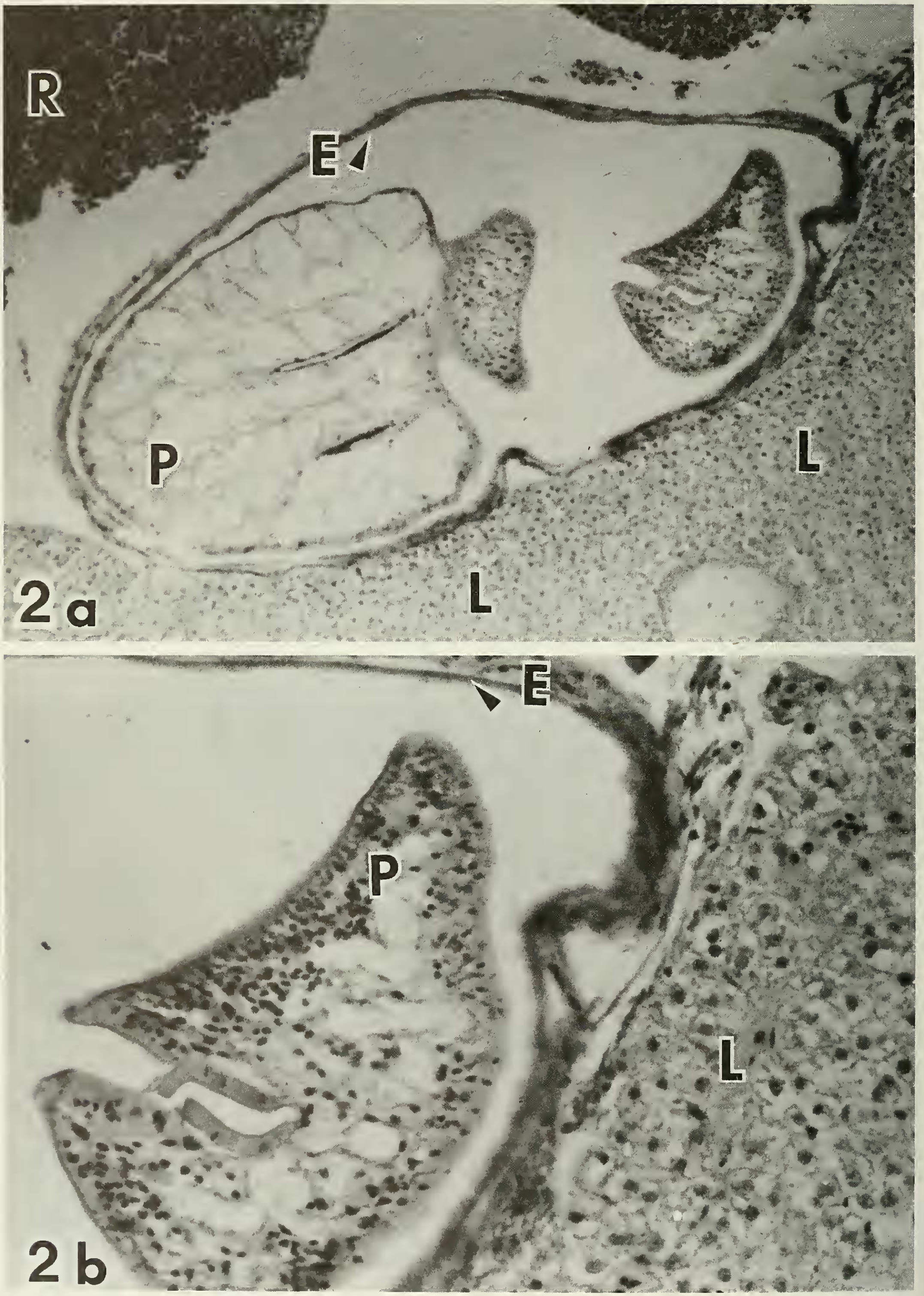

Fig. 2a, b. The metacercarial stage of *Posthodiplostomum minimum* (P) from the internal viscera of *Plagopterus argentissmus*. Note encapsulation (E) of the larval trematode and organ compression of the liver (L). Hemorrhaging (R) has occurred near the site of metacercarial encapsulation. Magnification, 2a—100X, 2b—430X.

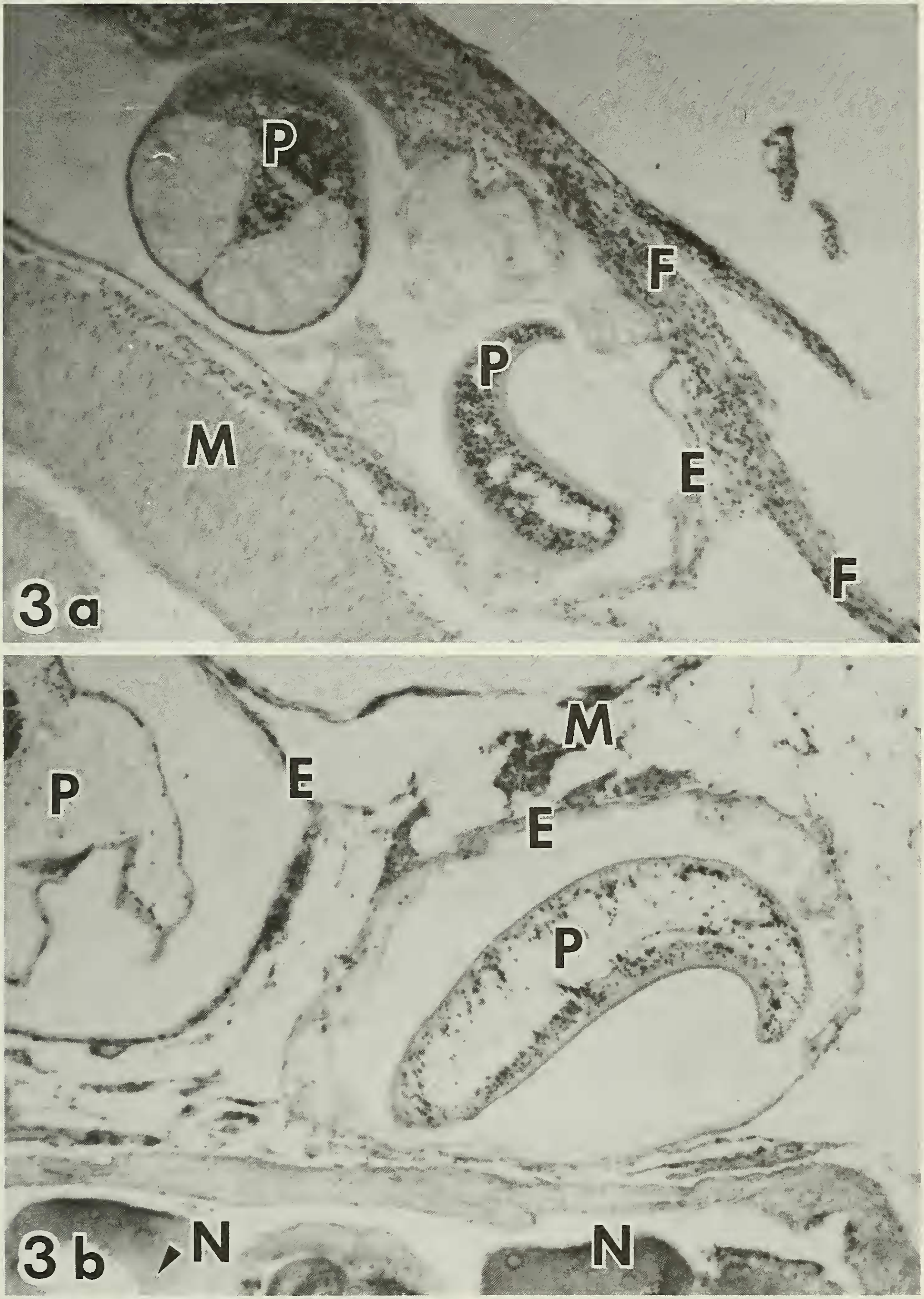

Fig. 3a, b. The larval stage of *Posthodiplostomum minimum* (P) from the internal viscera of *Plagopterus argentissmus*. 3a represents metacercariae encapsulated (E) in outer layer (F) (fibro serosa) of the intestinal tract. Note muscularis externa (M) (100X). 3b represents metacercariae encapsulated (E) in the mesentaries (M) of the viscera exhibiting compression on the intestine (N) (100X).

infection of *P. minimum* metacercariae, in Fife Lake, Michigan, dying in large numbers. This represents an example of a questionable cause-and-effect relationship because the parasite is ubiquitous and usually numerically abundant. More than circumstantial evidence is required to substantiate an allegation of *P. minimum* being a cause for fish mortality. Wild fish, with several hundreds of encysted metacercariae in the liver, sinus venosus, heart, and kidneys, are often observed to suffer no obvious debilitating effects. Colley and Olsen (1963) found as many as 991 metacercariae per bluegil, with metacercariae so dense as to be clumped en masse. Spall and Summerfelt (1969a) have observed 2,041 metacercariae in a bluegill from an Oklahoma reservoir.

Mortality due to stress and trauma from penetration of the cercariae has been observed in the laboratory following exposure of suitable host fish to high numbers of cercariae (Hunter 1937, Bedinger and Meade 1967). Host reactions following cercarial penetration include petechial hemorrhage at the site of invasion followed by congestion of surrounding venules and local edema, and an aggregation of leucocytes at the point of entry, particularly the phagocytic elements. Pathological effects include increased rate of excretion, increased plasma globulin and albumin, increased liver respiration, and decreased hematocrits (Smitherman 1964). Hemorrhage or a decrease in erythropoiesis would reduce hematocrits. The increase in the plasma proteins may represent a homeostatic response to the nutritional demands of the parasite, altered liver function, or effects on capillary permeability.

After encystment (19 days), mortality infrequently occurs. There is no experimental evidence to indicate mortality or other detrimental effects from the occurrence of encysted metacercariae.

Bothriocephalus acheilognathi = (*B. gowkongenesis* = *B. opsalichthydes*)

The Asian fish tapeworm, *Bothriocephalus acheilognathi*, represents a new introduction in North America, brought in through imports of grass carp to this country from China. Because of the new introduction and size of the adult worm, this parasite has become of major concern to fish and game officials throughout the country. Excellent reviews of the histopathology, biology, life history, control, and management of *Bothriocephalus* are found in a series of papers by Nakajima and Egusa (1947a, b, c, 1976a, b).

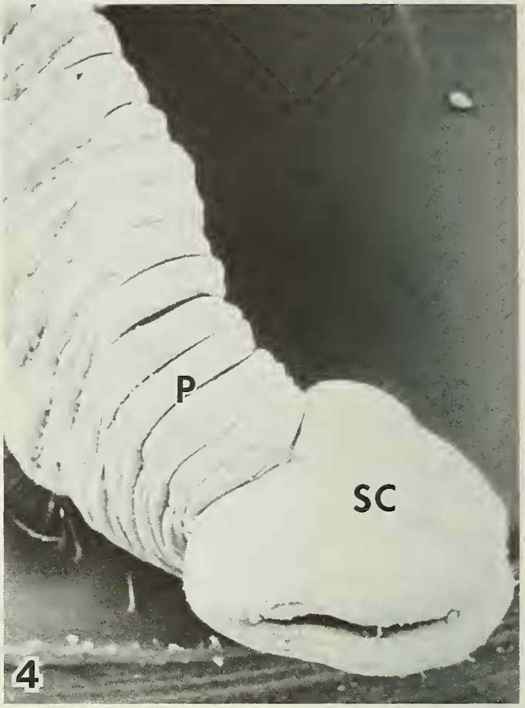

Fig. 4. A scanning electron micrograph of the Asian fish tapeworm, *Bothriocephalus acheilognathi*, from the intestine of the Virgin River roundtail chub, *Gila robusta seminuda*. Note the pit-viper shaped scolex (SC) and numerous proglottids (P). Photographed at 100X magnification.

The Asian fish tapeworm, characterized by its arrow or heart-shaped scolex (Fig. 4), has been a dangerous parasite for cultured grass carp and German carp fingerlings in Europe (Bauer et al. 1981). In Europe it has also been found in European catfish, guppies, mosquito fish, and other species (Hoffman 1983, Hoffman and Shubert 1984). In the United States it has been found in golden shiners and fathead minnows (Hoffman 1976), as well as in grass carp, Colorado squawfish, and mosquito fish. We add speckled dace, roundtail chub, Virgin spinedace, woundfin, and red shiner to that list.

The best known carp parasite transported to the fish ponds of many countries with the

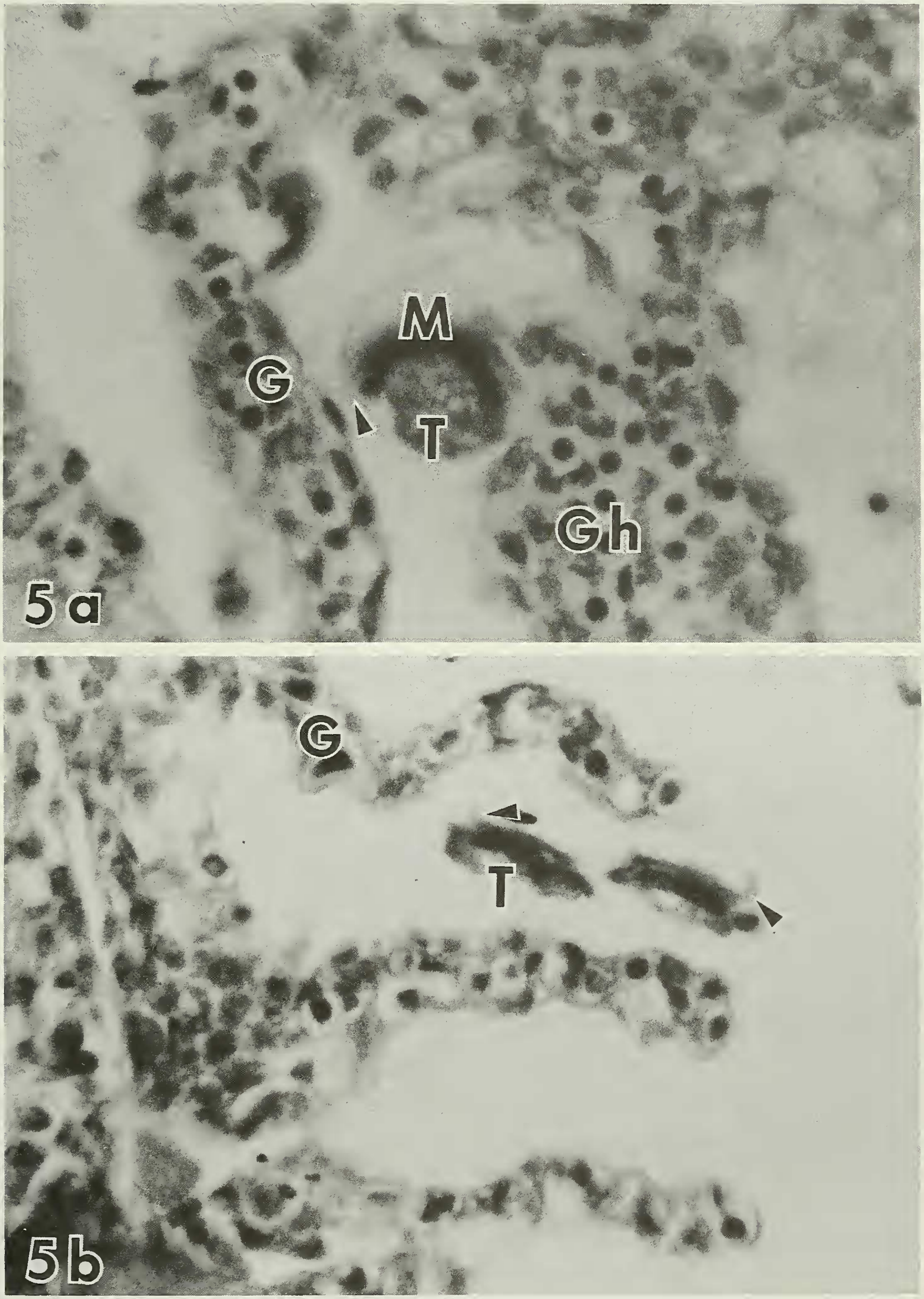

Fig. 5a, b. *Trichodina* (T) infesting the gill lamellae (G) of *Plagopterus argentissmus*. Note the macronucleus (M) and cilia (arrow) characteristic of this ciliate. There is tissue granulation and hypertrophy (gh) of the host gill tissue near one parasite. 1000X magnification.

Chinese carp is *Bothriocephalus acheilognathi* (= *B. gowkongensis*, = *B. opsalichthydis*) (Bauer et al. 1981). All European countries that culture carp in large quantities now have this pathogen. The spread of this parasite to new localities usually results in heavy infection of young fishes during the first years after it appears. *Bothriocephalus acheilognathi*, a thermophyllic parasite, can infect many fish species. Presumably it traveled to the United States by airplane in grass carp shipped from Asia.

Trichodina: Trichodinosis

This is a ciliated protozoan that was commonly observed on the gills of the woundfin minnow in August (Table 2).

This ciliate is ubiquitous among fish parasites throughout the world and usually is of minor concern for fish health. Members of the genus *Trichodina* Ehrenbert (Family; Urceolariidae Stein) are commonly seen on all kinds of aquatic animals. In fish they may settle on the skin in such numbers as to obscure the normal structure (Fig. 5a, 5b), and they are easily recognized by their similarity to a suction disk. Classification methods have been reviewed by Tripathi (1954). *Trichodina* parasitizes the skin, gills, and urinary bladder of the fish and is found both in freshwater and the sea.

The species of *Trichodina* that occur on North American freshwater fishes have not received the attention that they have in other areas of the world even though they are one of the most important groups of ectoparasites of freshwater fishes. Frequent references to trichodinids parasitizing fish occur in fish culture literature but the species are not named, as in the case for our study. Only Mueller (1937, 1938), David (1947), Lom (1963), Lom and Hoffman (1964), Hoffman (1967), and Wellborn (1967) have made major contributions to the knowledge of the taxonomy and distribution of *Trichodina* of North American freshwater fishes. Because of their small size, supposed lack of specific characters, and difficulty of removal from their hosts, they have been largely ignored.

More than 90 species of *Trichodina* have been described from the skin and gills of marine and freshwater fishes of the world (Hoffman 1967, Wellborn 1967). Many of these were described as new only because they were found on a different host or in another geographic location. In many cases the descriptions were inadequate since the uniform body structure of these ciliates yields few characters for differentiation of the species (Lom 1961, 1970, Mueller 1937). The inexact and insufficient descriptions of most early authors make the identification of many species doubtful. But the recently employed silver-impregnation technique of Klein and Chatton-Lwoff (Corliss 1953) reveals details of the adhesive disk that are important features of trichodinid taxonomy. Padnos and Nigrelli (1942) used the silver-impregnation technique to determine the ciliar patterns of trichodinids. But, according to Lom (1958), Raabe (1950) was the first to employ this technique in the study of the structure of the adhesive disk.

Trichodina rarely give rise to pathological manifestations of disease. It may be sporadically found in living fish, but it will only multiply in moribund and weakened ones. A macronucleus, mironucleus, and numerous food vacuoles are to be seen in the cytoplasm.

In our study we observed *Trichodina* on the gill surface (Fig 5a, 5b) of woundfin minnows in August.

DISCUSSION

Deacon and Hardy (1984) referred to segments of the Virgin River above Washington Diversion and above Mesquite Diversion as relatively undisturbed. Segments of the river below these two diversions were referred to as disturbed largely by irrigation withdrawals. Table 7 demonstrates that mean and minimum flows in May-November were substantially reduced at Bloomington below the Washington Diversion in 1985. Table 8 demonstrates a similar reduction in flow at Riverside, below the Mesquite Diversion in 1979. In addition, water quality in disturbed segments of Virgin River is also reduced, largely as a consequence of its use for agricultural irrigation (Sandberg and Sultz 1985). In June 1985 discharge from a salt spring (Pah Tempe Spring) suddenly increased dramatically, resulting in degradation of water quality throughout the Utah portion of the Virgin River (Table 9). Therefore, our 1979 data clearly contrast parasite loads in fishes ex-

TABLE 7. Provisional mean, maximum, and minimum daily discharge (cfs) of the Virgin River at Hurricane and Bloomington, Utah, in 1985.

	Hurricane			Bloomington		
Month	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	197	361	150	238	433	198
February	201	266	145	220	301	169
March	270	515	153	276	574	171
April	637	982	330	673	1,050	285
May	229	462	103	202	477	63
June	96.9	179	68	44.2	150	25
July	116	565	78	71.2	481	31
August	86.7	91	78	37.4	49	28
September	79.1	125	73	54	132	32
October	76.7	149	52	91.1	142	73
November	183	696	56	191	808	88
December	171	286	84	198	319	119

TABLE 8. Mean, maximum, and minimum daily discharge (cfs) of the Virgin River at Littlefield, Arizona, and Riverside, Nevada, in 1979.

	Littlefield			Riverside		
Month	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	200	458	139	257	591	178
February	324	389	256	376	447	279
March	603	2,440	252	656	2,440	280
April	1,262	1,840	760	1,111	1,580	692
May	1,559	2,000	962	1,277	1,580	789
June	390	815	79	213	652	1.2
July	68.9	79	63	1.23	18	0
August	127	637	70	23.3	150	0
September	65.9	68	63	9.37	27	0
October	92.3	128	65	50.3	118	17
November	171	211	137	184	225	138
December	194	219	173	192	242	150

TABLE 9. Specific conductance, Virgin River, pre- and postdevelopment of a dramatic increase of flow from Pah Tempe Springs.

	Predevelopment		Postdevelopment
Location of water sample	Hickman 1984–85	Sandberg and Sultz 1985	Hickman 1985
Pah Tempe Springs	16,000–17,500	12,600–13,000	
Below Pah Tempe	5,900–6,600	850–4,430	9,400–10,900
Below Ash Creek	1,500–1,800	905–3,700	6,500–7,900
Above Quail Creek	1,600–2,100	825–3,140	5,000–8,000
Hurricane Bridge or Berry Springs	1,600–1,900	850–3,120	3,900–5,000
Above wash diversion or at inlet	1,600–1,900	820–3,450	3,900–6,500
Above Twin Bridges or above Fort Pierce Wash	1,700–2,200	890–4,390	4,000–5,000
Below Bloomington	2,000–2,2000	870–4,200	3,900–4,800

posed to nearly natural conditions near Beaver Dam Wash with fishes exposed to reduced flow and water quality near Mesquite. Our 1985 data, though designed to contrast the same environmental conditions in a different segment of Virgin River, have the additional complication of a sudden reduction in water quality throughout the entire Utah segment of the river one to two months prior to the time of our collections. Nevertheless, it is clear that the parasite burden in fishes of Virgin River living in more disturbed habitats is much higher than for the same species living in less disturbed habitats.

Cestodes (*Bothriocephalus acheilognathi*) occurred in all Cyprinids inhabiting the lower mainstream of the Virgin River in Arizona and Nevada in 1979 (Tables 5, 6). The exotic red shiner, *Notropis lutrensis*, was infected more frequently and with a greater number of cestodes per individual than were all native species except the Virgin roundtail chub, *Gila robusta seminuda*. Infection frequency and density were variable seasonally, with heaviest parasite loads in general occurring in fall and winter and lightest parasite loads in summer (Tables 5, 6). The woundfin in the "disturbed" segment of the lower mainstream (Table 6) was more heavily infected than was the population in the "undisturbed" segment (Table 5). The red shiner was equally heavily infected in both river segments (Tables 5, 6).

In 1985 cestodes were not detected in woundfin minnows at any of the four locations sampled in Utah. Since we sampled only during late July and August, it is possible that the absence of cestodes reflects only seasonal variation. Both frequency and density of trematode infection in woundfin, however, are much greater in the lower, more disturbed portion of the river near St. George (Table 2).

The reduced flows near St. George may force fish into slow-flowing pools or ponded waters. The more ponded conditions probably permit the development of dense populations of cercariae that are released by snails, an intermediate host in the trematode life cycle. These same conditions make the fish more vulnerable to piscivorous birds, facilitating completion of the trematode life cycle.

The degraded water quality resulting from agricultural return flows may also increase stress on the fish population, which may manifest itself in an increased parasite load. If this is a significant factor, the increased total dissolved solids from increased flows of Pah Tempe Springs beginning in summer 1985 (Table 9) may result in an increased parasite burden in fishes throughout the Utah portion of the Virgin River.

The discovery of the Asian fish tapeworm, *B. acheilognathi*, in the fish population of the Virgin River is of major concern. The parasite was probably introduced into the U.S. by the grass carp. It is considered to be especially dangerous in Europe, where it was also introduced. W. L. Minckley (personal communication) reports that it is especially damaging to Colorado squawfish at the Dexter National Endemic Fish Hatchery in Deming, New Mexico. The high incidence of infection with large numbers of tapeworms in the endangered roundtail chub near Beaver Dam Wash (Table 5) demonstrates the probability that it is similarly damaging to roundtail chubs. Other native fish species showed lower incidence of infection, but all cyprinids were infected at levels that could severely damage the populations. The exotic red shiner was as susceptible to infection at the roundtail chub.

Of the 17 chubs we examined from the river near St. George in July and August 1985, only 3 (18%) contained Asian fish tapeworms. We suggest that this is most likely a reflection of the fact that the tapeworm is just beginning to establish itself in the Utah segment of the river. The tapeworm probably arrived in the spring of 1984 along with the red shiner, *Notropis lutrensis*, which first appeared in April collections of fish from the Virgin River. Red shiners first became common in the St. George portion of the Virgin River during the summer of 1985. They were one of the most heavily infected species in the lower river in 1979 (Tables 5, 6). Twenty-four of 88 red shiners (27%) collected from the lower Virgin River near Mesquite, Nevada, on 15 August 1985 contained 37 adult Asian tapeworms. The red shiner, an excellent host for the Asian tapeworm, was recently established in the Utah portion of the Virgin River and probably brought the cestode into Utah.

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LITERATURE CITED

AVAULT, J. W., JR., AND R. ALLISON. 1965. Experimental biological control of a trematode parasite of bluegill. Expt. Parasitol. 17: 296–301.

BAUER, O. N., S. EGUSA, AND G. L. HOFFMAN. 1981. Parasitic infections of economic importance in fishes. Pages 425–443 *in* W. Slusarski, ed., Review of advances in parasitology. Polish Academy of Science.

BEDINGER, C. A., JR., AND T. G. MEADE. 1967. Biology of a new cercaria for *Posthodiplostomum minimum* (Trematoda: Diplostomidae). J. Parasitol. 53: 985–988.

BOYCE, N. P., AND S. BEHRENS YAMADA. 1977. Effects of a parasite *Eubothrium salvelini* (Cedstoda: Pseudophyllidea) on the resistance of juvenile sockeye salmon (*Oncorhynchis nerka*) from Banine Lake, British Columbia. Canadian J. Fish. Aquat. Sci. 34: 706–709.

BOYCE, N. P., AND W. C. CLARKE. 1983. *Eubothrium salvelini* (Cestoda: Pseudophyllidea) impairs seaward adaptation of migrant sockeye salmon yearlings *Oncorhynchus nerka* from Banine Lake, British Columbia. Canadian J. Fish. Aquat. Sci. 40: 821–824.

CHENG, T. C. 1973. General parasitology. Academic Press. 965 pp.

COLLEY, F. C., AND A. C. OLSON. 1963. *Posthodiplostomum minimum* (Trematoda: Diplostomidae) in fishes of lower Otay Reservoir, San Diego County, California. J. Parasitol. 49: 149.

CORLISS, J. O. 1953. The Chatton-Lwoff silver impregnation technique. Stain Tech. 28: 97–100.

DAVIS, H. S. 1936. Pathological studies on the penetration of the cercaria of the strigeid trematode, *Diplostomum flexicaudum*. J. Parasitol. 22: 329–337.

______. 1947. Studies of the protozoan parasites of freshwater fishes. U.S. Dept. Interior Fishery Bull. #41: 1–29.

DEACON, J. E., AND T. B. HARDY. 1984. Streamflow requirements of woundfin (*Plagopterus argentissimus*): Cyprinidae in the Virgin River, Utah, Arizona, Nevada. Festschrift for Walter W. Dalquest. Pages 45–56 *in* N. V. Horner, ed. Midwestern State University Press.

DOGIEL, V. A. 1958. Ecology of parasites of freshwater fishes. *In* Parasitology of fishes. Oliver and Boyd, Edinburgh.

______. 1964. General parasitology. Oliver and Boyd, Edinburgh and London.

DOMBROSKI, E. 1955. Cestode and nematode infection of sockeye smolts from Banine Lake, British Columbia. J. Fish. Res. Bd. Canada 12: 93–96.

FERGUSON, M. S. 1938. Experimental studies on *Posthodiplostomum minimum* (MacCallum, 1921), a trematode from herons. J. Parasitol. 24 (Suppl.): 31.

GREGER, P. D. 1983. Food partitioning among fishes of the Virgin River. Unpublished thesis, University of Nevada, Las Vegas.

HECKMANN, R. A. 1983. Eye fluke (*Diplostomum spathaceum*) of fishes from the Upper Salmon River near Obsidian, Idaho. Great Basin Nat. 43: 675–683.

HOFFMAN, G. L. 1958. Experimental studies on the cercaria and metacercaria of a strigeid trematode, *Posthodiplostomum minimum*. Expt. Parasitol. 7: 23–50.

______. 1967. Parasites of North American freshwater fishes. University of California Press, Berkeley and Los Angeles. 486 pp.

______. 1976. The Asian tapeworm, *Bothriocephalus gowkongenesis*, in the United States, and research needs in fish parasitology. Proceedings Fish Farming Conference and Annual Convention Catfish Farmers of Texas, Texas A & M University 1976: 84–90.

______. 1983. Asian fish tapeworm, *Bothriocephalus opsarichthydis*, prevention and control. Fish Disease Leaflet: USFWS: USDA: 1–4.

HOFFMAN, G. L., AND G. SCHUBERT. 1984. Some parasites of exotic fishes. Pages 233–261 *in* W. R. Courtney and J. R. Staffer, eds., Distribution, biology, and management of exotic fishes. Johns Hopkins University Press, Baltimore and London.

HUGHES, R. C. 1928. Studies on the trematode family Strigeidae (Holostomidae) No. IX. *Neascus van cleavei* (Agersborg). Trans. Amer. Micro. Soc. 47: 320–341.

HUNTER, G. W., III. 1937. Parasitism of fishes in the lower Hudson area. Pages 264–273 *in* A biological survey of the lower Hudson watershed. Biological Survey No. XI (1936), Suppl. to the Twenty-sixth Ann. Rept., New York State Conservation Dept.

______. 1940. Studies on the development of the metacercaria and the nature of the cyst of *Posthodoplostomum minimum* (MacCallum, 1921) (Trematoda; Streigeidae). Trans. Amer. Micro. Soc. 59: 52–63.

LOM, J. 1958. A contribution to the systematics and morphology of endoparasitic trichodinids from amphibians, with a proposal of uniform specific characteristics. J. Protozool. 5: 251–263.

______. 1961. Protozoan parasites found in Czechoslovakian fishes. I. Myxosporidia, Suctoria. ool. Listy Fol. Zool. 10(24): 45–58.

______. 1963. The ciliates of the family Urceoloariidae inhibiting gills of fishes (the Trichodinella-group). Acta Soc. Zool. Bohemoslov. 27: 7–19.

______. 1970. Observations on trichodinid ciliates from freshwater fishes. Archiv f_r Protistenkunde 112: 153–177.

LOM, J., AND G. L. HOFFMAN. 1964. Geographical distribution of some species of Trichodinids (Ciliata: Peritricha) parasitic on fishes. J. Parasit. 50: 30–35.

MILLER, J. H. 1954. Studies on the life history of *Posthodiplostomum minimum* (MacCallum, 1921). J. Parasitol. 40: 255–270.

MUELLER, J. F. 1937. Some species of Trichodina (Ciliata) from freshwater fishes. Trans. Amer. Micr. Soc. 56: 117–184.

______. 1938. A new species of *Trichodina* (Ciliata) from the urinary tract of the muskalonge, with a repartition of the genus. J. Parasit. 23: 251–258.

NAKAJIMA, K., AND S. EGUSA. 1974a. *Bothriocephalus opsariichthydis* Yamagutii (*Cestoda: Pseudophyllidea*) found in the gut of cultured carp, *Cyprinus carpio* (Linne)—I. Morphology and taxonomy. Fish Pathology 9(1): 31–39.

______. 1974b. *Bothriocephalus opsariichthydis* Yamagutii (*Cestoda: Pseudophyllidea*) found in the gut of cultured carp, *Cyprinus carpio* (Linne)—II. Incidence and histopathology. Fish Pathology 9(1): 40–45.

_____. 1974c. *Bothriocephalus opsariichthydis* Yamagutii (*Cestoda: Pseudophyllidea*) found in the gut of cultured carp, *Cyprinus carpio* (Linne)—III. Anthelmintic effects of some chemicals. Fish Pathology 9(1): 46–49.

_____. 1976a. *Bothriocephalus opsariichthydis* Yamagutii (*Cestoda: Pseudophyllidea*) found in the gut of cultured carp, *Cyprinus carpio* (Linne)—IV. Observations on the egg and coracidium. Fish Pathology 11(1): 17–22.

_____. 1976b. *Bothriocephalus opsariichthydis* Yamagutii (*Cestoda: Pseudophyllidea*) found in the gut of cultured carp, *Cyprinus carpio* (Linne)—V. Ovicial effects of drying, freezing, ultraviolet rays, and some chemicals. Fish Pathology 11(1): 23–26.

PADNOS, M., AND R. F. NIGRELLI. 1942. *Trichodina spheroidesi* and *Trichodina halli* spp. nov. parasitic on the gills and skin of marine fishes, with special reference to the life-history of *T. spheroidesi*. Zoologica 27: 65–72.

RAABE, Z. 1950. Uwagi o Ureceolariidae (Ciliata-Peritricha) skrzel ryb. Ann. Univ. M. Curie-Sklodowska, Lublin 5: 292–310.

REES, G. 1967. Pathogenesis of adult cestodes. Helminth. Abstracts (36): 1–23.

SANDBERG, G. W., AND L. G. SULTZ. 1985. Reconnaissance of the quality surface water in the Upper Virgin River Basin, Utah, Arizona, and Nevada. 1981–82. Utah Dept. of Natural Resources Tech. Bull. 83: 1–69.

SMITH, H. D. 1973. Observations of the Cestode Eubothrium salvelini in juvenile sockeye salmon (*Oncorhynchus nerka* Walbaum) at Banine Lake, British Columbia. J. Fish. Res. Bd. Canada 30: 947–964.

SMITH, H. D., AND L. MARGOLIS. 1970. Some effects of *Eubothrium salvelini* Schrank (1970) on sockeye salmon (*Oncorhynchus nerka* Walbaum) in Banine Lake, British Columbia. J. Parasitol. 56(11): 321–322.

SMITHERMAN, R. O., JR. 1964. Effects of infections with the strigeid trematode, *Posthodiplostomum minimum* (MacCallum), upon the bluegill, *Lepomis macrochirus* Rafinesque. Unpublished dissertation, Auburn University, Auburn, Alabama. 55 pp.

SPALL, R. D., AND R. C. SUMMERFELT. 1969a. Host-parasite relations of certain endoparasitic helminths of the channel catfish and white crappie in an Oklahoma reservoir. Bull. Wild. Dis. Assoc. 5: 48–67.

_____. 1969b. Life cycle of the white grub, *Posthodiplostomum minimum* (MacCallum 1921: Trematoda, Diplostomatidae), and observations on host-parasite relationships of the metacercariae in fish. Pages 218–230 *in* S. F. Snieszko, ed., A symposium of diseases of fishes and shellfishes. Special Publ. No. 5 AFS.

TRIPATHI, Y. R. 1954. Studies on parasites of Indian fishes. III. Protozoa. 2. (Mastigophora and ciliophora). Rec. Indian Mus. 52: 221–230.

WARDLE, R. A. 1933. The parasitic helminths of Canadian animals: the Cestodaria and Cestoda. Canadian J. Res. 8: 317–333.

WELLBORN, T. L., JR. 1967. *Tricodina* (Ciliata: Urceolariidae) of freshwater fishes of the southeastern United States. Journal of Protozoology 14(3): 399–412.

WILLIAMS, H. H., AND O. HALVORSEN. 1971. The incidence and degree of infection of *Gadus morhua* L. 1758 with *Aborthrium gadi* Beneden 1871 (Cestoda Pseudophyllidea). Norway J. of Zoology 19: 193–199.